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GEODYNAMICS

Applications of Continuum Physics to Geological Problems

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pressure p of rock in the mantle is given by the simple hydrostatic equation

$$p = \rho g y \tag{1-1}$$

where ρ is the density of the mantle rock, g is the acceleration of gravity, and y is the depth. The solidus temperature (the temperature at which the rock first melts) decreases with decreasing pressure. When the temperature of the ascending mantle rock equals the solidus temperature, melting occurs, as illustrated in Figure 1-6. The ascending mantle rock contains a low-melting-point, basaltic component. This component melts to form the oceanic crust.

Problem 1-2 At what depth will ascending mantle rock with a temperature of 1800°K melt if the equation for the solidus temperature T is

$$T(°K) = 1700 + 0.12p\,(\mathrm{MPa})$$

Assume $\rho = 3300$ kg m^{-3}, $g = 10$ m s^{-2}.

The *magma* (melted rock) produced by partial melting beneath an ocean ridge is lighter than the residual mantle rock, and buoyancy forces drive it upward to the surface in the vicinity of the ridge crest. A large magma chamber is formed. Heat is lost to the seafloor, and this magma solidifies to form the oceanic crust. In some localities slices of oceanic crust and underlying mantle have been brought to the surface. These are known as *ophiolites*; they occur in such locations as Cyprus, Newfoundland, Yemen, and New Guinea. Field studies of ophiolites have provided a detailed understanding of the oceanic crust and underlying mantle. Typical oceanic crust is illustrated in Figure 1-7. The crust is divided into layers 1, 2, and 3, which were originally associated with different seismic velocities but which were subsequently identified compositionally. Layer 1 is composed of sediments that are deposited on the volcanic rocks of layers 2 and 3. The thickness of sediments increases with distance from the ridge crest; a typical thickness is 1 km. Layers 2 and 3 are composed of basaltic rocks of nearly uniform composition. A typical composition of an ocean basalt is given in Table 1-1. The basalt is composed primarily of two rock-forming minerals, plagioclase feldspar and pyroxene. The plagioclase feldspar is 50 to 85% anorthite

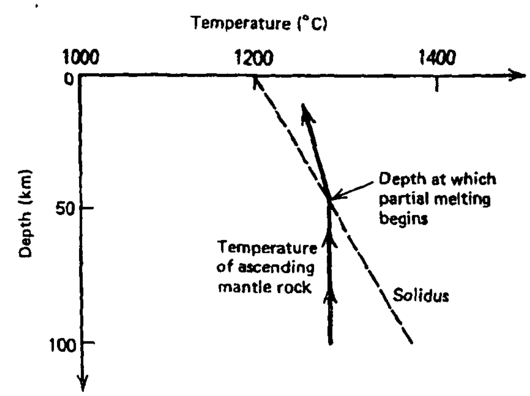

Figure 1-6 The process of pressure-release melting is illustrated. Melting occurs because the nearly isothermal ascending mantle rock encounters pressures low enough so that the associated solidus temperatures are below the rock temperatures.

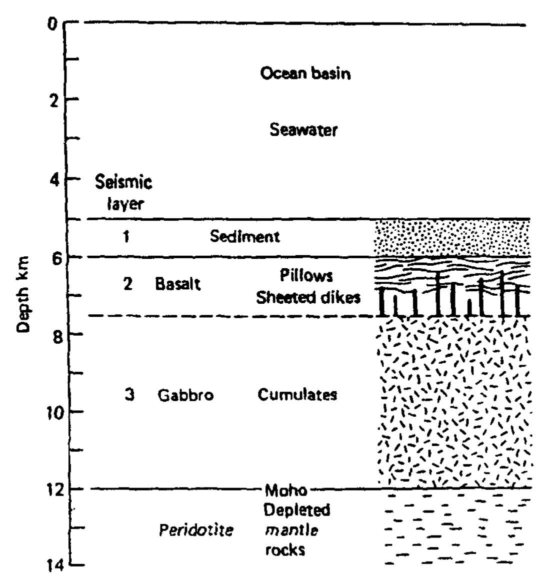

Figure 1-7 Typical structure of the oceanic crust, overlying ocean basin, and underlying depletec mantle rock.

E. PROPERTIES OF ROCK

	Density kg m^{-3}	E 10^{11} Pa	G 10^{11} Pa	ν	k W m^{-1} °K^{-1}	α 10^{-5} °K^{-1}
Sedimentary						
Shale	2100–2700	0.1–0.3	0.14		1.2–3	
Sandstone	2200–2700	0.1–0.6	0.04–0.3	0.2–0.3	1.5–4.2	3
Limestone	2200–2800	0.6–0.8	0.2–0.3	0.25–0.3	2–3.4	2.4
Dolomite	2200–2800	0.5–0.9	0.3–0.5		3.2–5	
Marble	2200–2800	0.3–0.9	0.2–0.35	0.1–0.4	2.5–3	
Metamorphic						
Gneiss	2,700	0.04–0.7	0.1–0.35	0.04–0.15	2.1–4.2	
Amphibole	3,000		0.5–1.0	0.4	2.5–3.8	
Igneous						
Basalt	2,950	0.6–0.8	0.3	0.25	1.3–2.9	
Granite	2,650	0.4–0.7	0.2–0.3	0.1–0.25	2.4–3.8	2.4
Diabase	2,900	0.8–1.1	0.3–0.45	0.25	1.7–2.5	
Gabbro	2,950	0.6–1.0	0.2–0.35	0.15–0.2	1.9–2.3	1.6
Diorite	2,800	0.6–0.8	0.3–0.35		2.8–3.6	
Pyroxenite	3,250				4.1–5	
Anorthosite	2,750	0.83	0.35	0.25	1.7–2.1	
Granidiorite	2,700				2.6–3.5	
Mantle						
Peridotite	3,250				2.3–3	2.4
Dunite	3,250	1.4–1.6	0.6–0.7		3.7–4.6	
Miscellaneous						
Halite			0.3	0.15	5.4–7.2	13
Ice			0.092	0.033	2.2	5

F. MANTLE PROPERTIES

Depth y km	Density ρ 10^3 kg m^{-3}	Pressure p 10^{11} Pa	Gravity g m s^{-2}	Temperature T °K	Young's Modulus E 10^{11} Pa	Shear Modulus G 10^{11} Pa	Compressibility β 10^{-12} Pa^{-1}	Poisson's Ratio ν
100	3.359	0.0314	9.864	1,610	1.618	0.631	8.065	0.282
200	3.420	0.0649	9.898	1,610	1.647	0.642	7.918	0.283
300	3.479	0.0988	9.931	1,680	1.883	0.725	6.411	0.299
400	3.540	0.1332	9.968	1,750	2.076	0.799	5.805	0.299
400	3.742	0.1332	9.968	1,910	2.459	0.940	4.694	0.308
500	3.866	0.171	9.990	1,975	2.702	1.039	4.430	0.300
650	4.051	0.231	10.009	2,075	3.088	1.197	4.078	0.290
650	4.365	0.231	10.009	2,375	4.126	1.622	3.318	0.272
800	4.454	0.295	9.992	2,412	4.384	1.720	3.089	0.274
1000	4.570	0.386	9.966	2,462	4.718	1.846	2.826	0.278